Jet Propulsion Laboratory
California Institute of Technology

Spacecraft Contamination Control Challenges for Space Missions with Organic Compound Detection Capabilities and for Potential Sample Return

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14th International Symposium on Materials in the Space Environment (ISMSE)
12th International Conference on Protection of Materials from Space Environment (ICPMSE)

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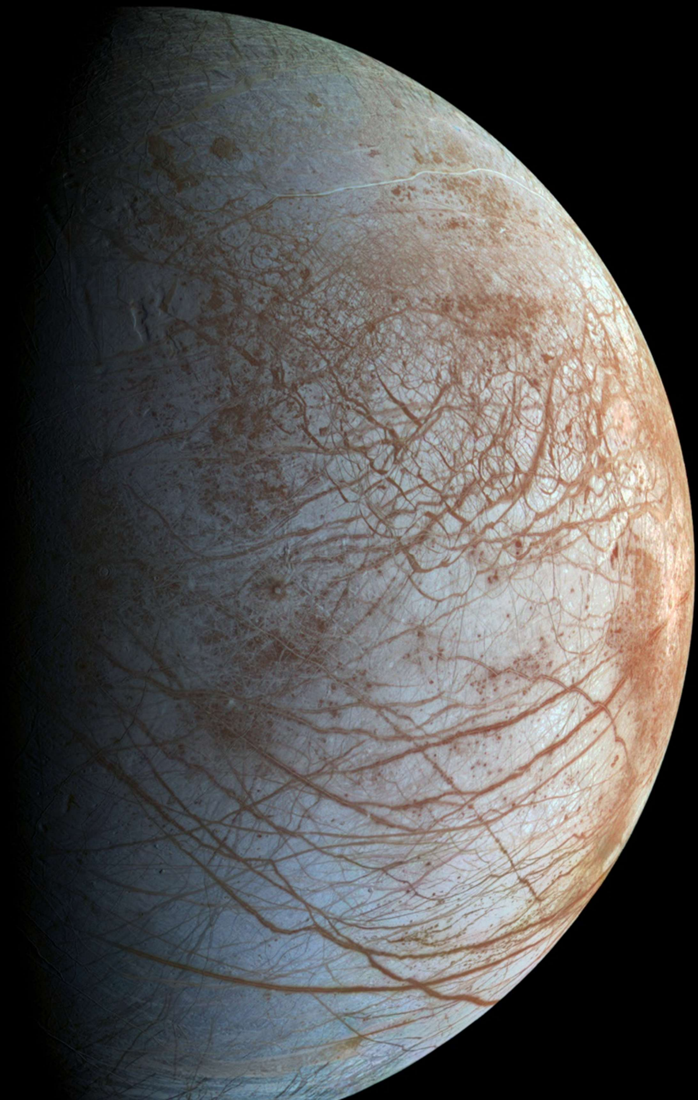

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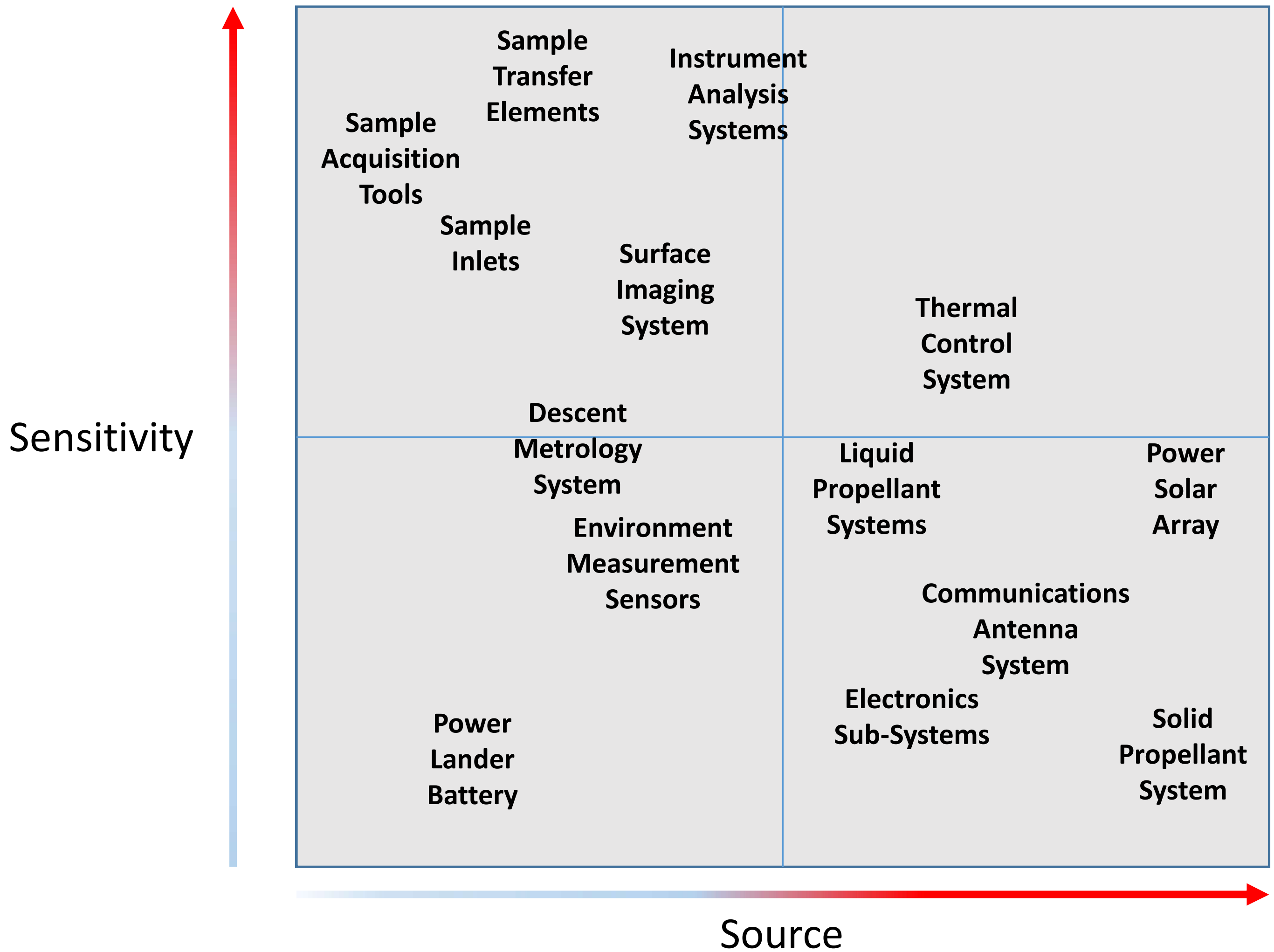
Introduction

- Contamination control is critical to missions with organic compound detection capabilities, and for missions targeting acquisition of samples for potential return to Earth
- Significant challenges are being addressed in the design of current flight projects and conceptual mission studies at JPL
- These challenges extend to both orbiting spacecraft, as well as landed missions, for future missions to Mars and Europa, and potential missions to Titan and Enceladus
- Contamination control during all phases of a mission, from preliminary design through operation, is fundamental to ensure that organic compounds of terrestrial origin are controlled to ensure successful completion of science objectives
- This presentation summarizes contamination control challenges specific to landed missions (which include sample acquisition, encapsulation, caching, potential sample return, and UV instruments), and orbiting missions (modeling interactions between the spacecraft, and local exospheres and plumes)

Contamination Sensitivities and Sources

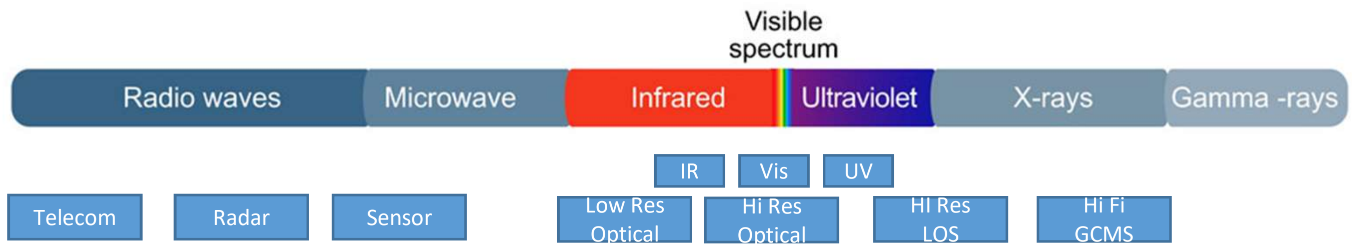


Contamination Control Key Mission Events

Event	Cause/Effect	Mitigation Mechanisms
Launch	Fairing and space vehicle depressurization redistributes particles to exposed sensitive surfaces	Reduction through use of covers and allowable particle loading of space vehicle and fairing surfaces
Bio barrier release	Exposure of sample chain to bio cover and deployment/ejection mechanisms	Reduction though local deployable covers, material controls
Cruise maneuvers	Cruise propulsion system firings, leakage	Reduction through configuration; baffles, view factors
Orbit insertion	Radiation induced outgassing, return flux molecular environment	Reduction through materials selection, processing; sensor/inlet view factors
Descent maneuver	Solid propellant effluents and accumulation on Lander surfaces	Reduction through covers, configuration; characterization of contaminants
Skycrane operations	Propulsion system firings, release mechanisms; accumulation on lander and landed surfaces	Reduction through covers, baffles; operational mitigations for sample acquisition
Sampling system/HGA deployment	Deployment actuations, materials (self contamination)	Reduction through local controls (capture features)
Surface operations	Transfer of surface contaminants to sample	Cleaning mechanisms, background measurement, sample blanks

Significant investment of design, modeling and operational analysis required to develop system architecture and operation profiles to achieve the desired mission objectives

Comparative Requirements based on Mission/Component Sensitivity



Factor	Low Sensitivity	Medium Sensitivity	High sensitivity*
Materials Selection	• Heritage materials • ASTM E595 screening criteria	• Early materials screening • Design constraints identified	• Design level implementation • ASTM E1559 selection criteria
Outgassing	• $<10^{-9}$ g/s/cm^2 • By analysis	• $<10^{-12}$ g/s/cm^2 • By analysis with measure/model	• $<10^{-15}$ g/s/cm^2 • By measurement with model
Materials thermal vacuum conditioning	• Time temperature profiles permitted • Open chamber accommodation	• QCM monitoring with T/t adjust • Tiered bakeout schemes	• TQCM/CQCM exit criteria • Extended bakeout, chamber config
Surface cleanliness (EOL)	• Optics: 650 B • Instrument: 750 A • General: 750 C	• Optics: 300 A • Instrument: 500 A/2 • General: 500 A	• Optics: <200 A/10 • Instrument: <300 A/5 • General: <300 A/2
Clean room/ Garment	• ISO 8 • Gown	• ISO 7 • Coverall	• ISO 7 to ISO 5 • Full

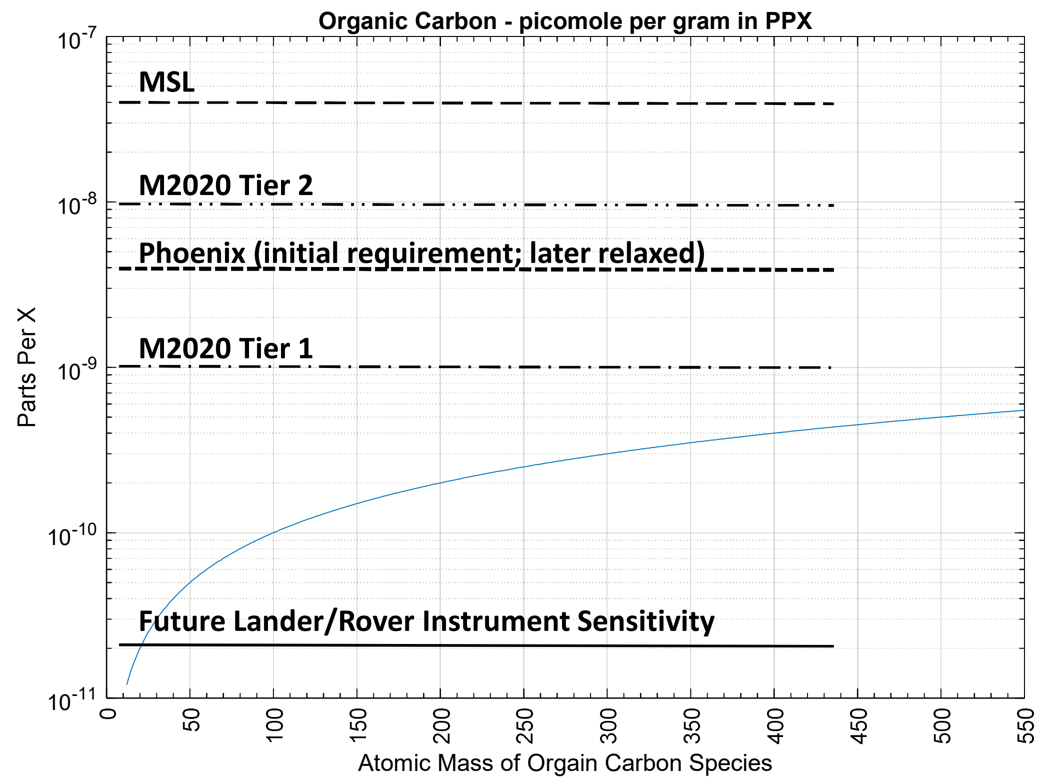
Notes:
Each level includes or considers lower level requirements

* Minimum; instrument sensitivity/science return may require order of magnitude or more further reduction

Contaminant Ratio Requirement Mission Comparison

- Phoenix:
  - Initially set to 4 ppb organics, but redefined to "best effort possible"
- Mars Science Laboratory:
  - 40 ppb organics
- Mars 2020:
  - 1 ppb "Tier I organics"
  - 10 ppb "Tier II organics"

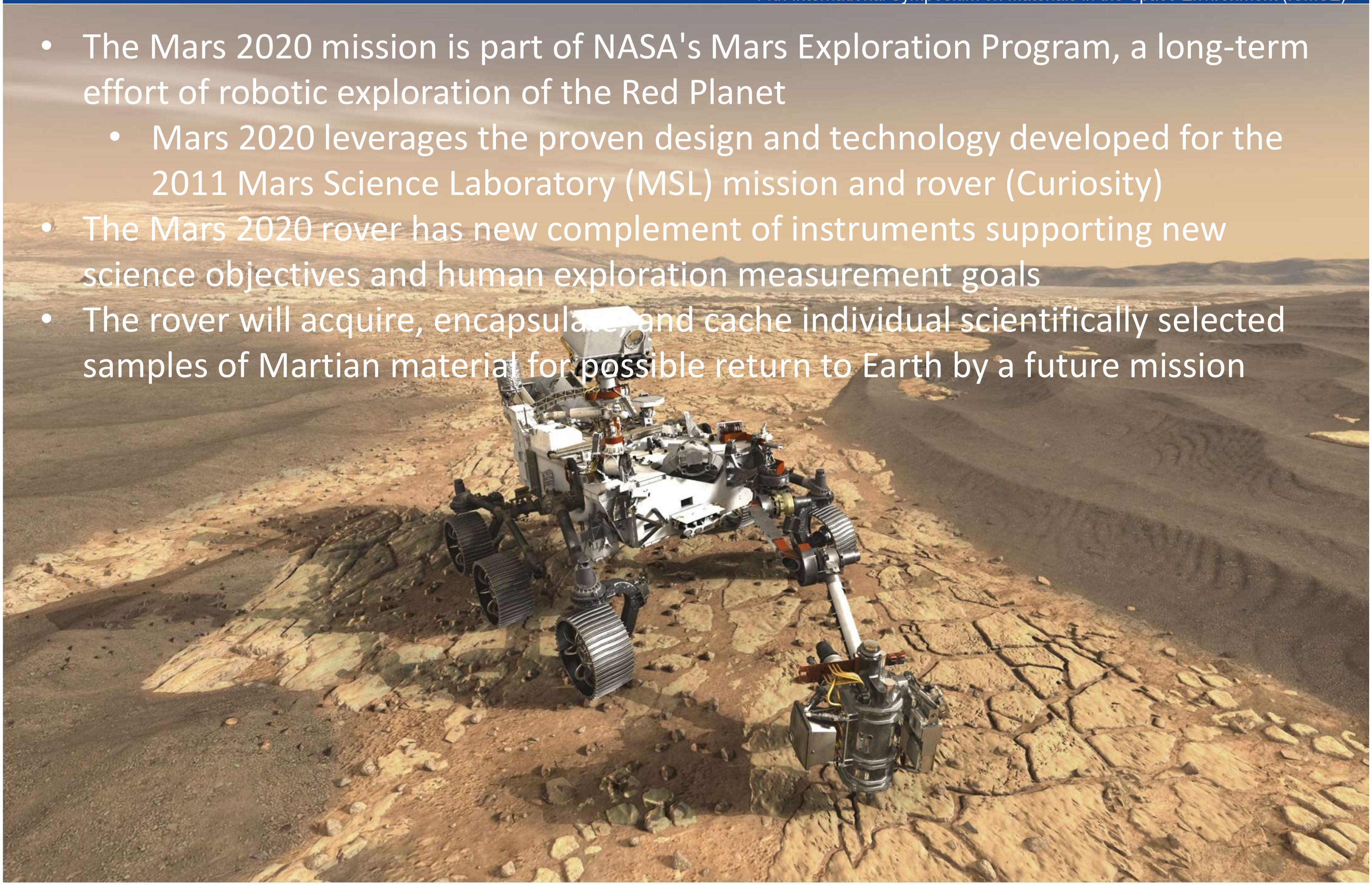
- **Future lander/rover missions: <10 pptr**



Two or more orders of magnitude decrease in contamination from Mars 2020 Tier 1 levels

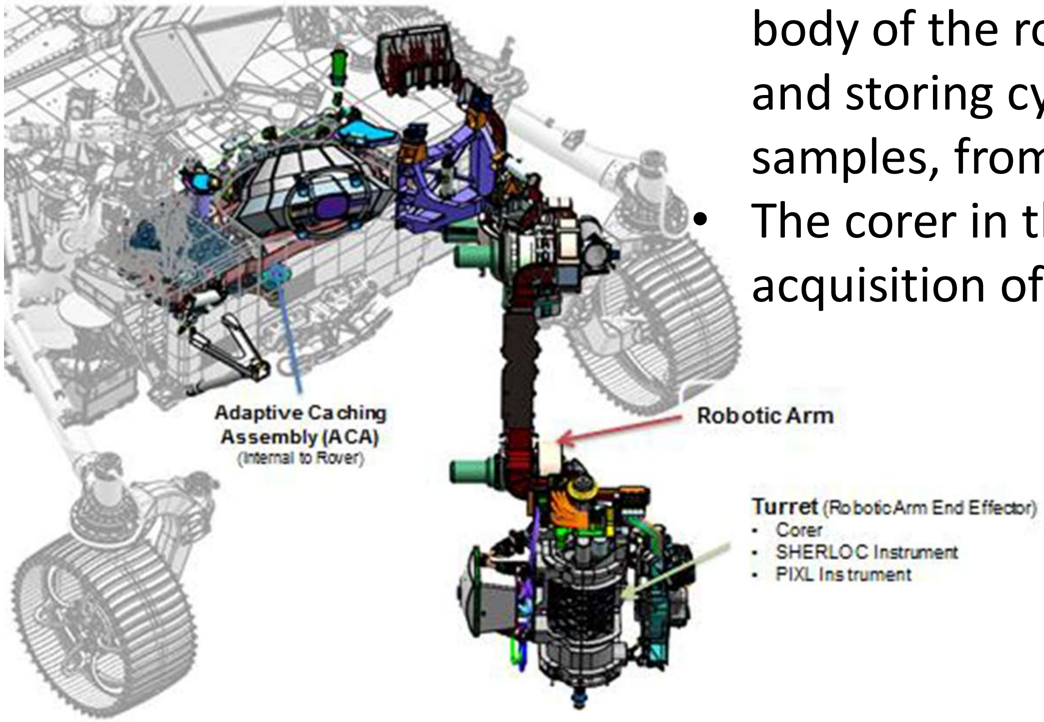
Mars 2020

- The Mars 2020 mission is part of NASA's Mars Exploration Program, a long-term effort of robotic exploration of the Red Planet
  - Mars 2020 leverages the proven design and technology developed for the 2011 Mars Science Laboratory (MSL) mission and rover (Curiosity)
- The Mars 2020 rover has new complement of instruments supporting new science objectives and human exploration measurement goals
- The rover will acquire, encapsulate, and cache individual scientifically selected samples of Martian material for possible return to Earth by a future mission



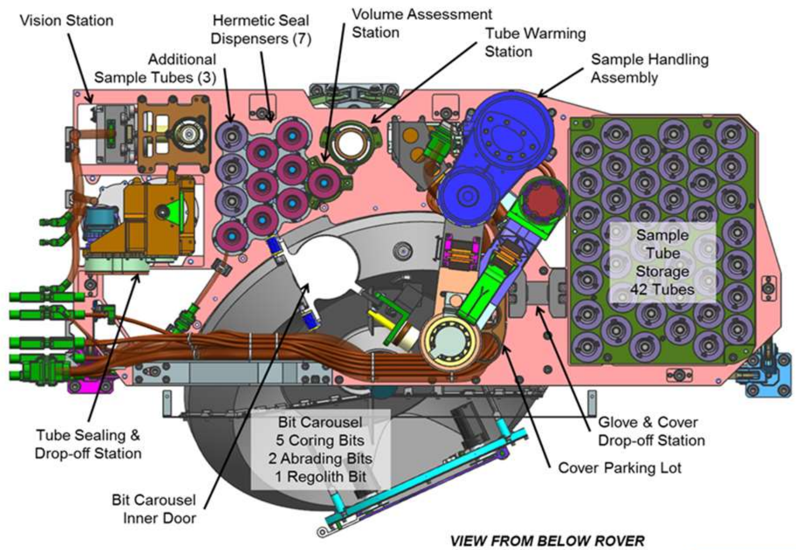
Sample acquisition, encapsulation and caching

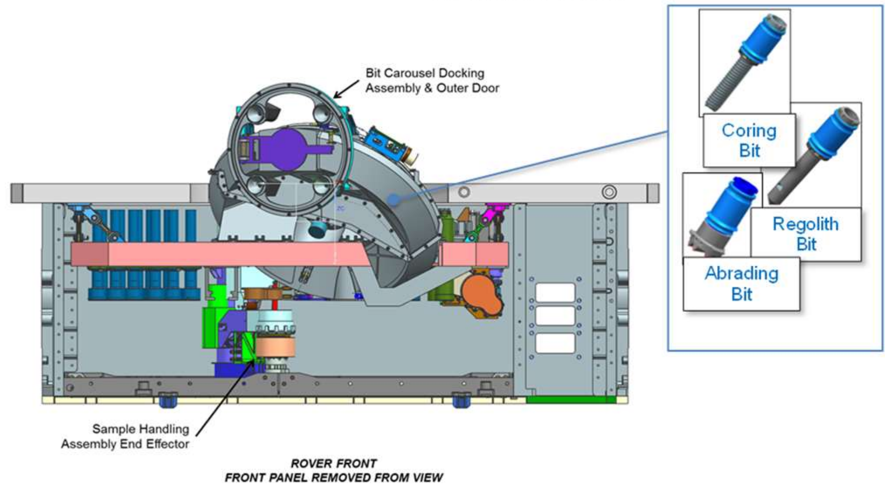
- The design of the sample collection system must be effective in minimizing and limiting the accumulation of contaminants prior to sample collection
- Mars 2020 will be the first mission intended to collect scientific samples from the surface of Mars for potential return to Earth
- The Adaptive Caching Assembly (ACA) within the body of the rover will be responsible for acquiring and storing cylindrical sections of rock, or core samples, from the Martian surface
- The corer in the robotic arm will be used for acquisition of Martin samples



Sample acquisition, encapsulation and caching (cont.)

- The samples will be individually encapsulated and sealed in sample tubes in the Tube Sealing and Drop Off Station
- The sample acquisition process occurs in a precise sequence, with the ACA working in conjunction with the rotary percussive drill
- A sample tube is extracted and inserted into a hollow drill bit
- As the rotary percussive corer drills into the Martian surface, the core sample is forced into the clean sample tube
- The process is complete with the sealing of the sample tube





Sample acquisition, encapsulation and caching (concluded)

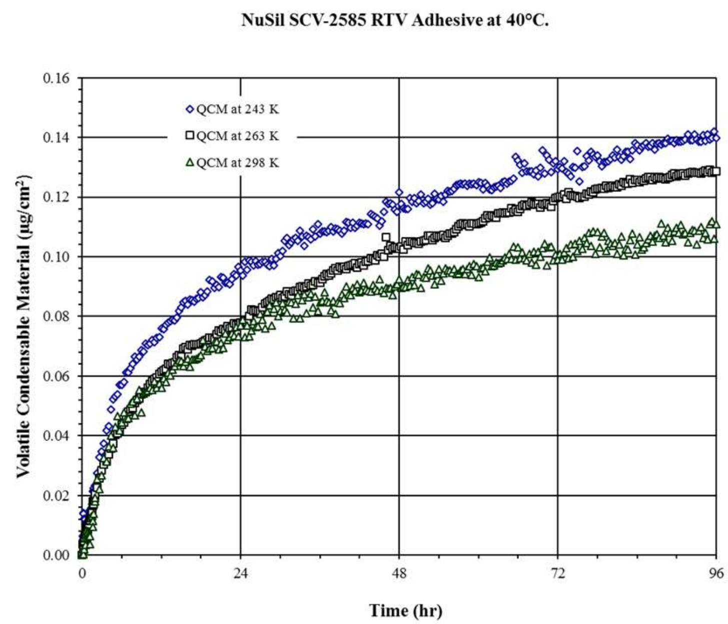
- Several methods were used to achieve the low levels of contamination required by this mission:
  - Selection of low outgassing materials
  - Reduction of outgassing rates through extensive vacuum baking
  - Use of preferential venting schemes to divert molecular effluents from outgassing
  - Use of molecular adsorber coatings within sample caching systems
  - Use of Low Surface Energy (LSE) coatings (TiN) on Low Surface Roughness (LSR) materials to minimize molecular deposition
  - Use of a Fluid Mechanical Particle Barrier (FMPB) in the sample tubes

Materials outgassing

- Characterization of outgassing rates through ASTM E1559 is critical for application to contamination sensitive missions
- The ASTM E1559 test method B allows for custom test parameters that are tailored to mission specific applications:
  - Outgassing source temperature selection within the operating temperature of the material
  - Thermoelectric Quartz Crystal Microbalance (TQCM) receive temperature simulating operating temperatures of contamination sensitive hardware of interest
  - Sufficiently long test duration to support development of outgassing rate decay models
  - QCM Thermo-Gravimetric Analysis (QTGA) of collected contaminant deposit
  - Mass spectrometer data collection during the test for identification of molecular effluent composition
- One of the major materials selection challenges for the Mars 2020 mission was in the selection of suitable materials for the sample collecting hardware that meet the strict inorganic and organic contamination limits
- This required limitations on the levels of approximately 20 elements (e.g., tungsten, sulfur) that are critical for the scientific study of cached samples
- Further, organic contaminants were assessed on the basis of total organic carbon and imposed limits on critical “Tier 1” organic compounds

Reduction of outgassing rates

- Vacuum baking non-metallic materials at the lowest levels of assembly is an effective technique to reduce outgassing rates to the required levels
- Monitoring of the vacuum bake-outs with QCMs until exit criteria are achieved is the most effective way to verify that molecular outgassing is controlled to the required levels
  - Vacuum chamber background levels need to be verified to ensure that exit criteria requirements can be met
- For Mars 2020, verifying outgassing rates down to the 1 ng/cm²/hour level, at stringent temperature limits (50° C for the hardware and -50° C for the QCM) presents a challenge, as vacuum chambers with sufficiently low background levels are not widely available



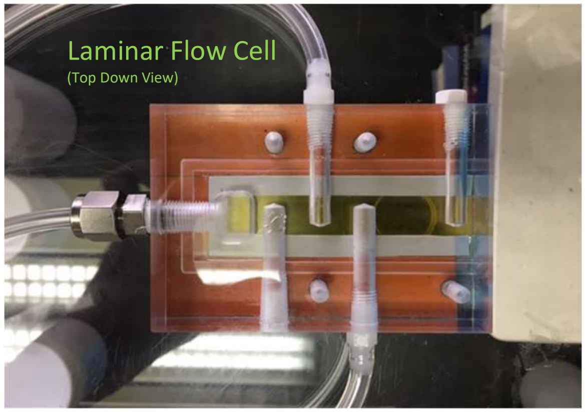
Post thermal vacuum bakeout at 60°C for 96 hours

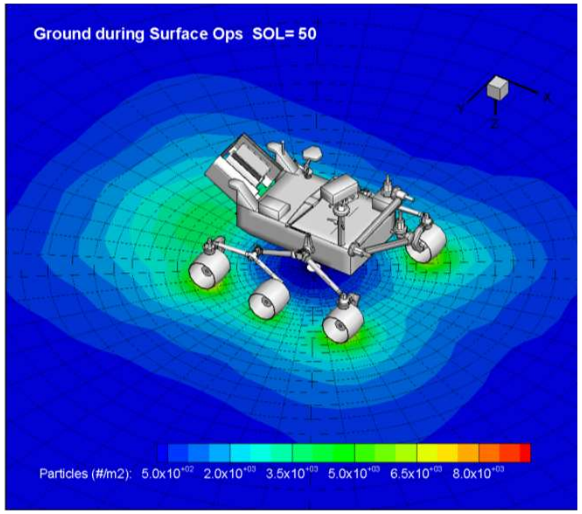
Molecular adsorbers

- Molecular adsorbers can be incorporated in the design to minimize contamination to sensitive surfaces by collecting molecular effluents
- For Mars 2020, the desired selection criteria for molecular adsorber were:
  - Hydrophobic properties to prevent molecular loading during Assembly, Test and Launch Operations (ATLO)
  - Ability to adsorb organic outgassing products (higher molecular weight) while exposed to vacuum during the long-duration cruise
  - Ability to absorb organic outgassing products in the Martian environment, without loading under the carbon dioxide atmosphere
- Tenax, a porous polymer resin based on 2,6-diphenyl-pphenylene oxide was evaluated, and ultimately selected, as an absorber to protect the Mars 2020 adaptive caching assembly (ACA) from outgassed molecular contamination
- Tenax is a well-documented absorber extensively used in analytical chemistry
  - Tenax absorbs compounds relevant to spacecraft and flown on spacecraft to trap organics for chemical analysis
- One of the application concerns that was addressed through a test program were the fabrication, mounting and mechanical stability (particle shedding) during launch

Particle resuspension modeling

- When subjected to wind on Mars, particles on the rover can be re-suspended and transported to the Martian surface.
  - Particles may carry organic compounds and terrestrial organisms which may contaminate Martian soil samples
- JPL has developed models to predict the resuspension of particles due to G-forces and wind shear
  - Experiments were performed to determine model parameters for real-life particles and spacecraft substrates
- An experimental set-up using a laminar flow cell is being used to generate a fully developed laminar flow in a rectangular channel
  - Particles are deposited onto slides and installed in the flow cell.
  - The flow cell is contained in a purge box to control humidity (which affects particle removal rates)
  - Microscope images are taken the particle removal fraction at various flow rates
- The JPL model, supported by extensive experimental data, is applied to characterize particle resuspension and transport under a wide range of Martian wind conditions



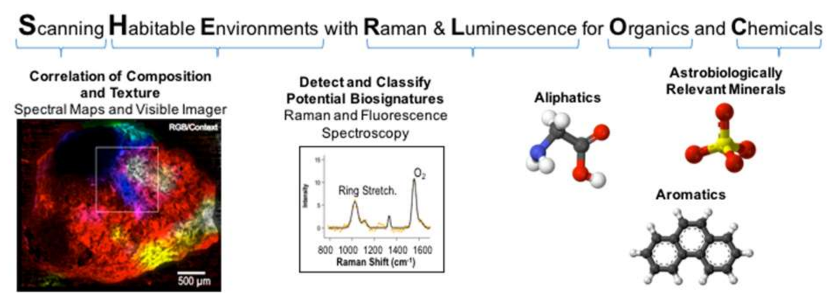


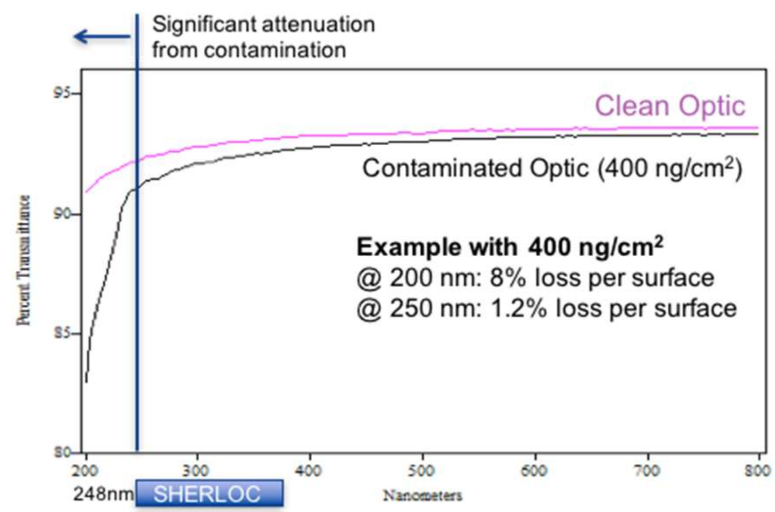
Challenges for potential sample return

- Achieving low levels of contamination on sample acquisition and collection systems is a significant challenge, and also critical to mission success
- Contamination limits limits based on the NASA Organic Contamination Panel (OCP) science recommendations for potential return of rock core samples are summarized as follows:
  - TOC: Total Organic Contamination, target <10 parts per billion (ppb)
  - Tier 1: Biomarker compounds are each limited to <1 ppb for any of 16 diagnostic compounds
  - Tier-2: Individual TOC components [except Tier-1], are limited to <10 ppb.
- Using a conservative assumption of a completely efficient (100%) transfer from sample intimate hardware with into the core samples, yields derived surface cleanliness limits approaching monolayer levels for Tier 1 compounds:
  - TOC <1ng/cm^2
  - Tier-1 <0.1ng/cm^2
  - Tier-2 <1ng/cm^2
- Given the low level of these limits, it is challenging to carry out quantitative analysis that can verify with high confidence that the hardware meets surface cleanliness requirements

Challenges for UV instruments
UV Raman spectroscopy and fluorescence

- Deep UV (DUV) resonance Raman and fluorescence spectrometers are highly sensitive to contamination
- The Mars 2020 SHERLOC is an instrument with unprecedented levels of sensitivity to condensed carbon and aromatic organics
    - SHERLOC analysis of the fluorescence spectra identifies number of aromatic rings present, and identifies regions of high organic content
    - Contamination control is critical to prevent condensation of contaminants on optical surfaces, and eliminate contaminants that would fluoresce in the UV
    - Mitigation methods include careful material selection, testing of all selected materials, and processing/vacuum baking materials to reduce outgassing
- Contamination induced transmission loss due to attenuation is a significant source of performance degradation for UV instruments





Europa Clipper

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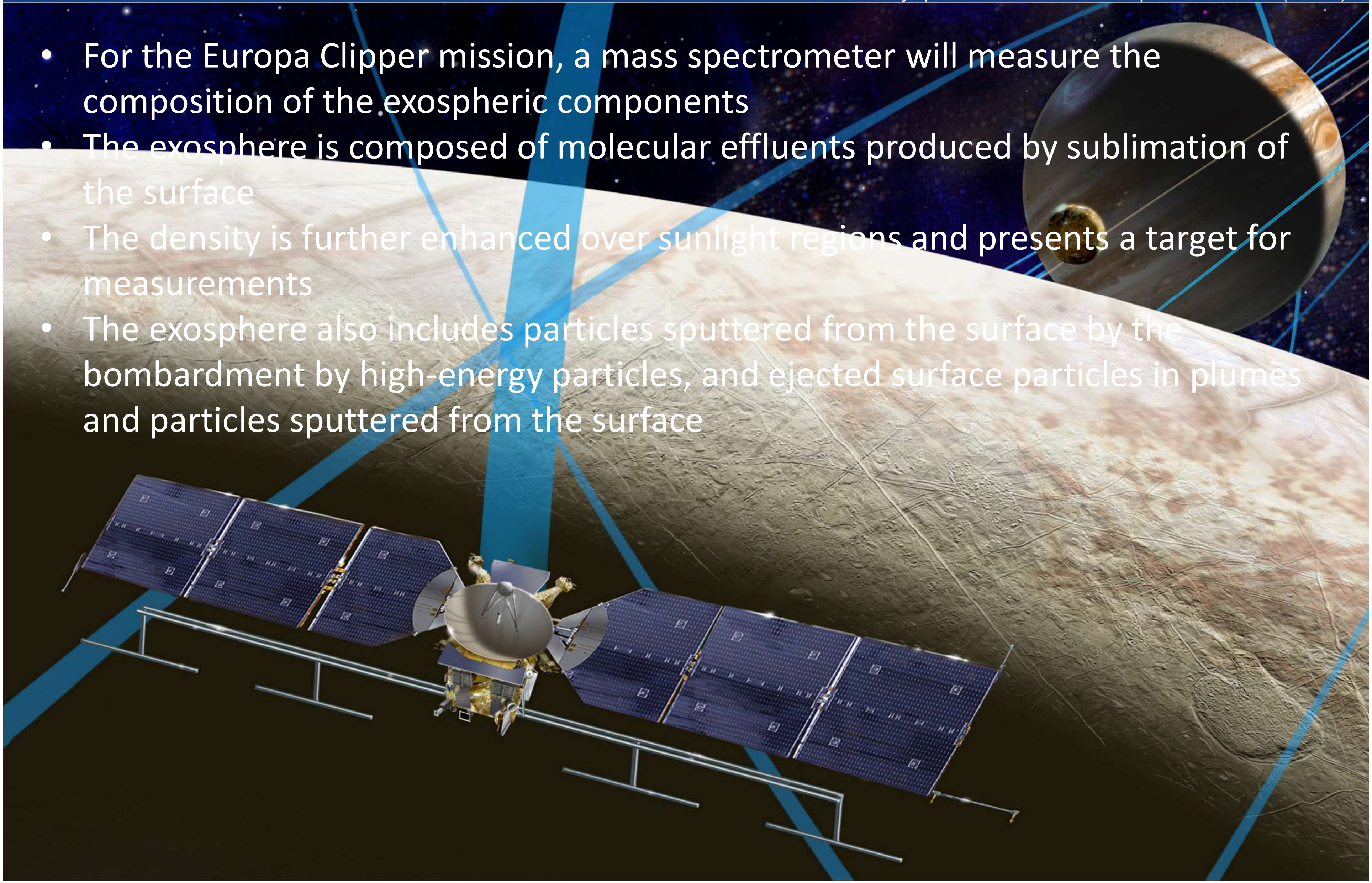
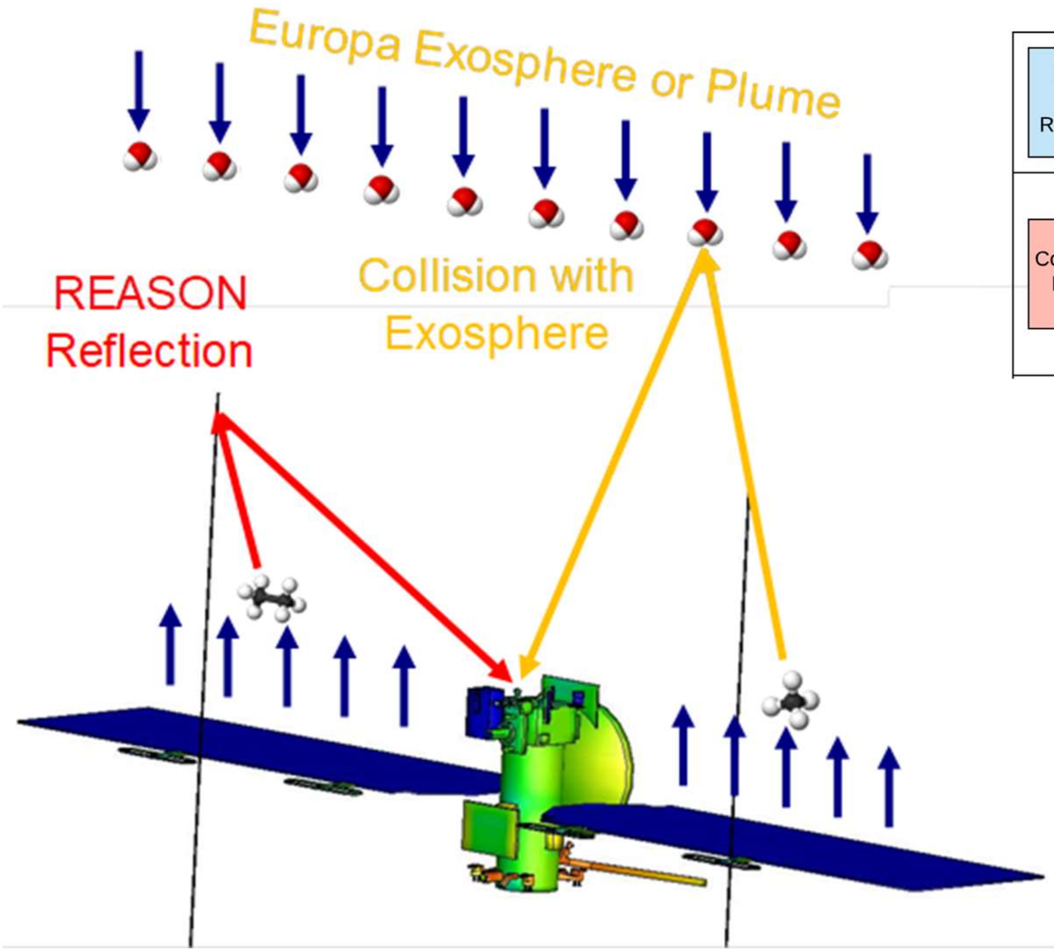
- For the Europa Clipper mission, a mass spectrometer will measure the composition of the exospheric components
- The exosphere is composed of molecular effluents produced by sublimation of the surface
- The density is further enhanced over sunlight regions and presents a target for measurements
- The exosphere also includes particles sputtered from the surface by the bombardment by high-energy particles, and ejected surface particles in plumes and particles sputtered from the surface

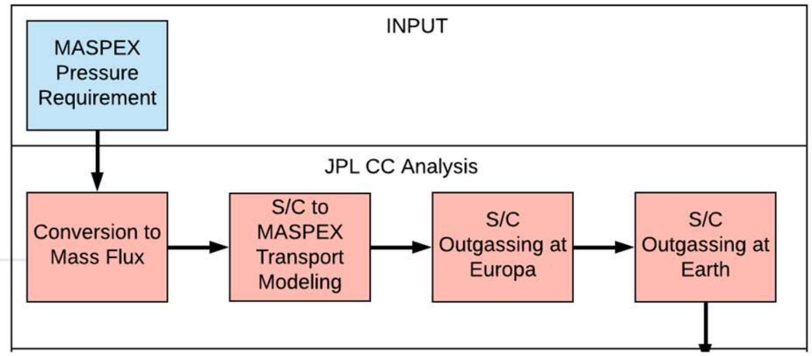


Return flux

- One of the Europa Clipper instruments will be a next-generation spectrometer with significantly improved capabilities when compared to existing instruments:
  - Extended mass range for heavy organic molecules
  - Enhanced mass resolution for critical isotopes
  - Enhanced dynamic range for high signal-to-noise ratios
  - Improved sensitivity for rare noble gases
  - High throughput for rapid descent probes
- Return flux of molecular emissions from spacecraft sources (such as materials outgassing and thruster firings) contribute to contaminant deposition onto contamination sensitive instruments.
- This contribution must be characterized to drive definition of contamination requirements for the spacecraft and the complement of instruments, and to support successful completion of science objectives

Contaminant Mass Flux Transport Mechanisms





There are three molecular transport mechanisms for Europa Clipper: direct flux, reflected flux, and return flux. MASPEX is affected by:

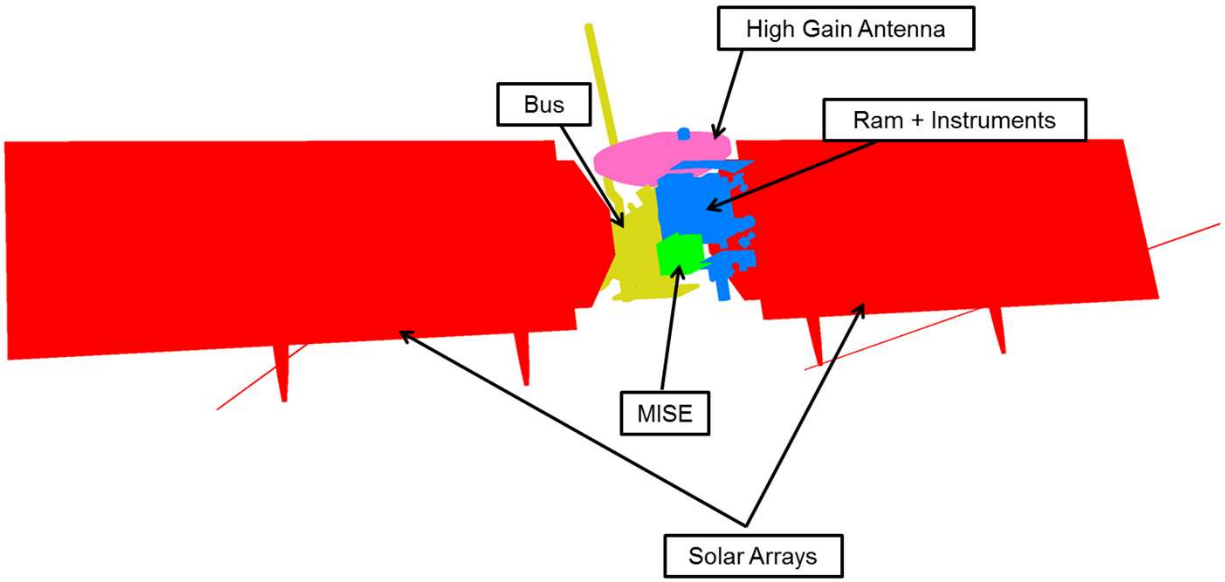
Reflected Flux: Contamination Transportation

- Source > REASON > MASPEX

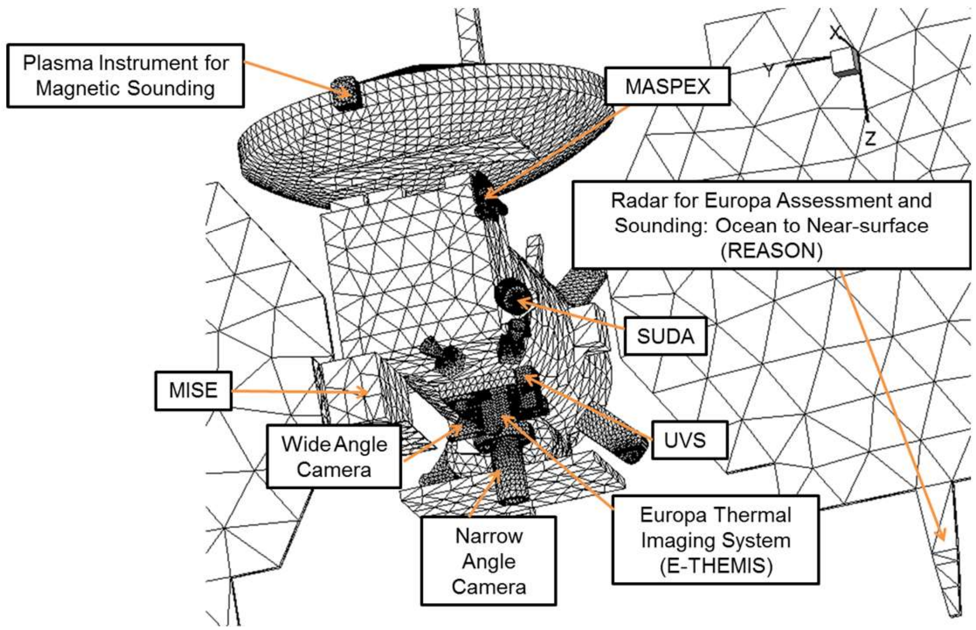
Return Flux: Contamination Transportation

- Source> Exosphere> MASPEX

Return flux



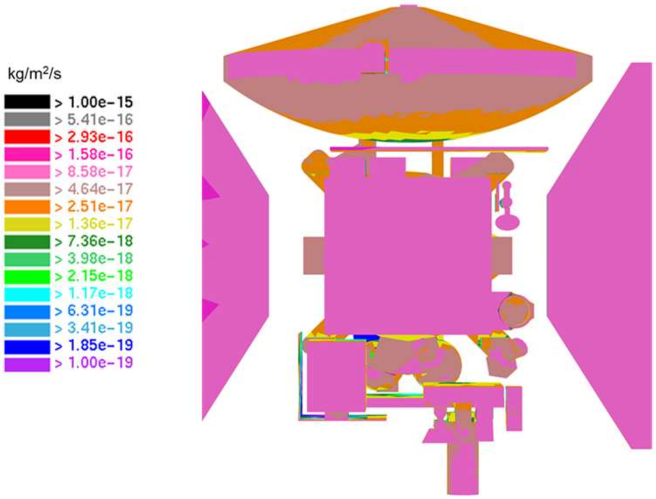
Major flight system contamination sources



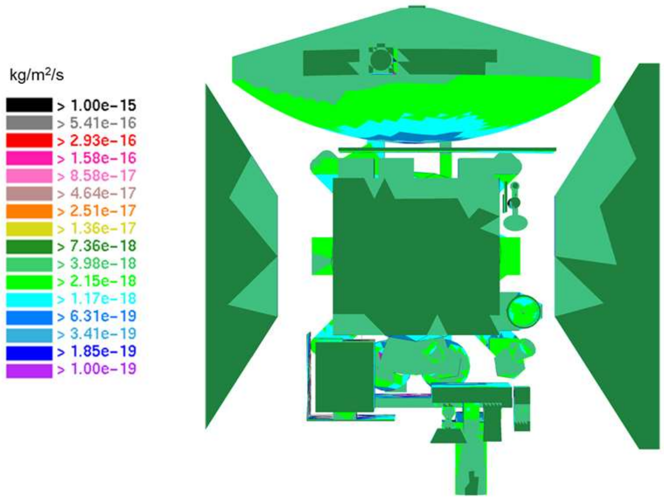
Mission science instruments

Relative Contributions from Major Spacecraft Contamination Sources [BGK]

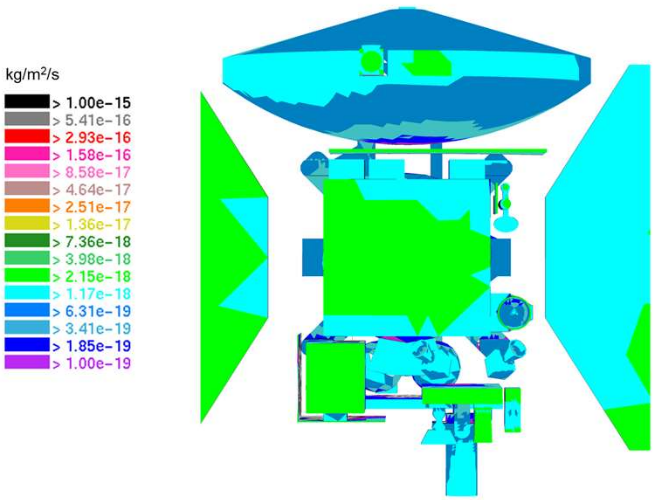
Case 1A Solar Array Contaminant 1 Return Flux



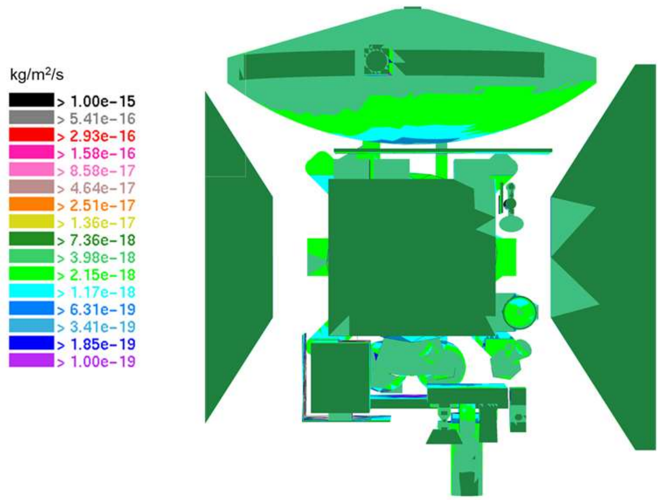
Case 1A Antenna Contaminant 1 Return Flux



Case 1A MISE Contaminant 1 Return Flux

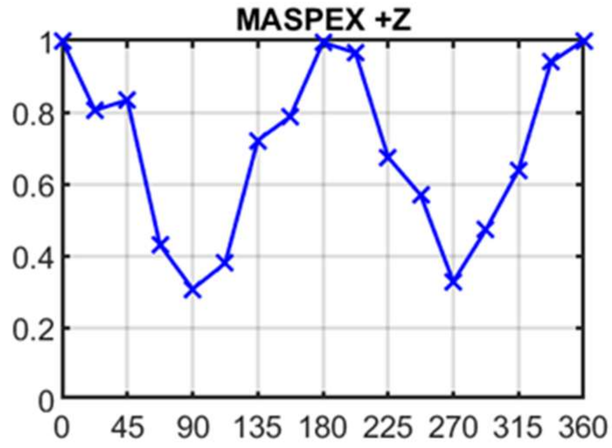


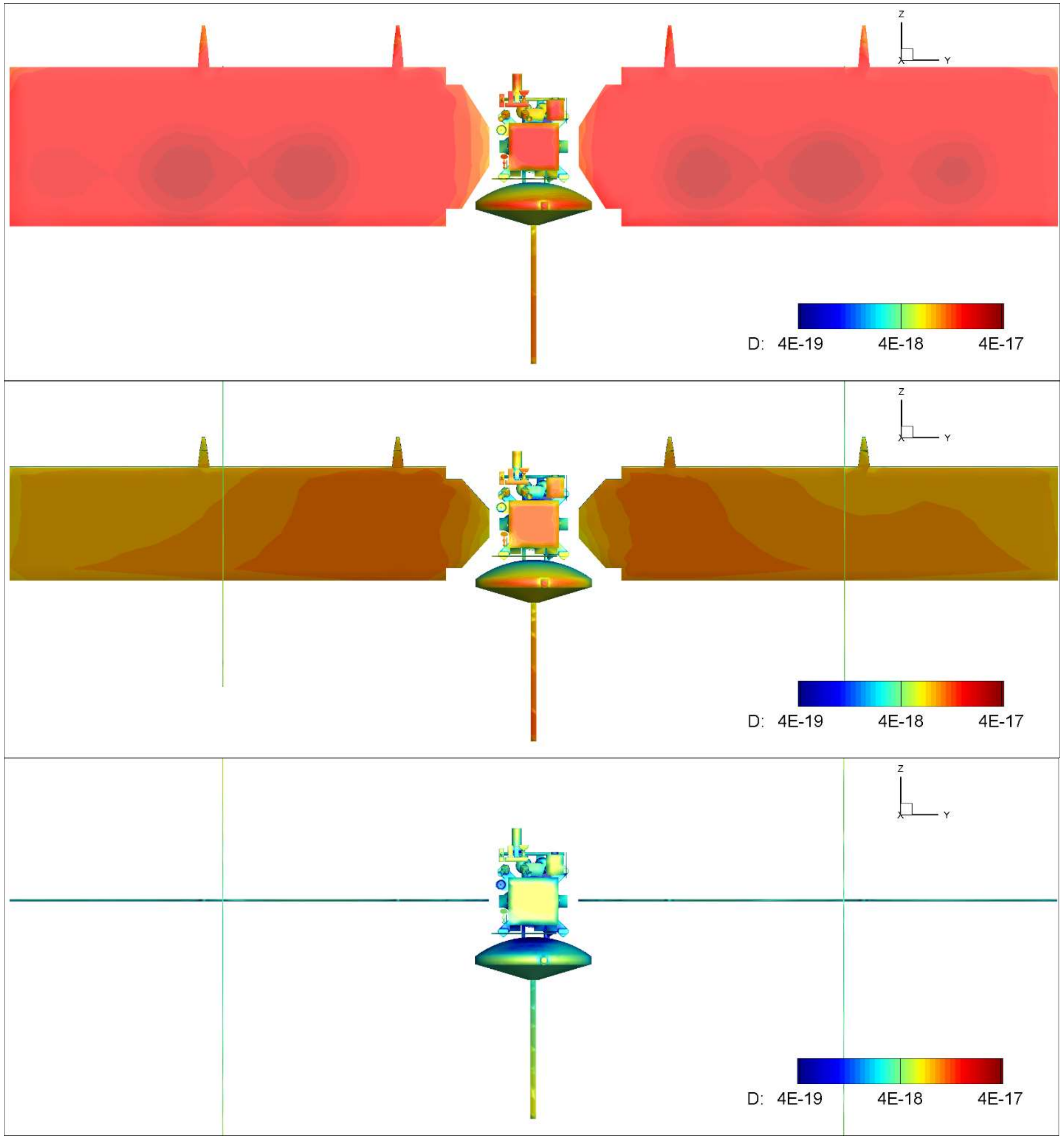
Case 1A Bus Contaminant 1 Return Flux



Notional results – for discussion only

Effects of Solar Array Orientation [BGK]

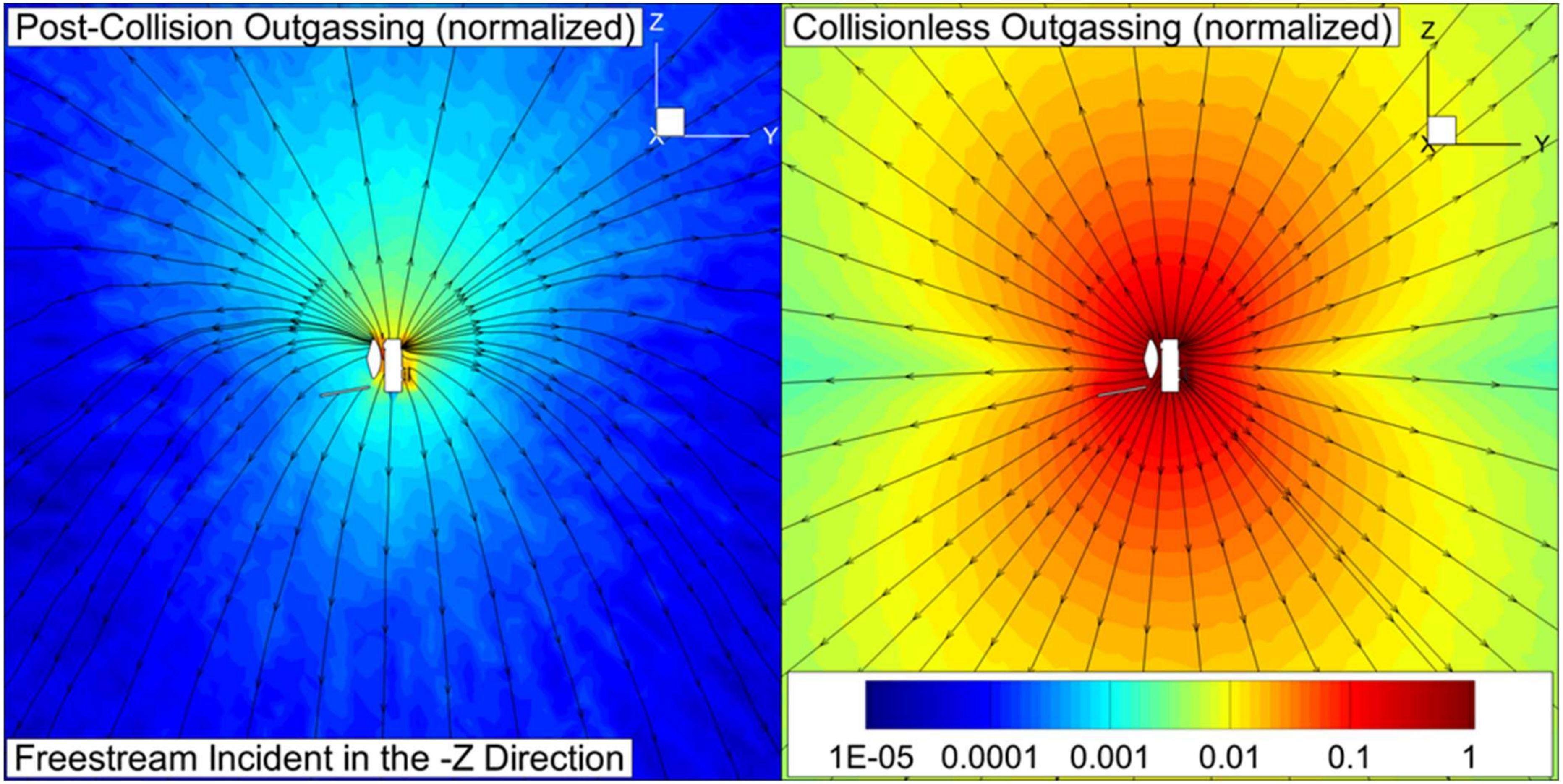




Notional results – for discussion only

Return flux [DSMC]

- DSMC solution of closest-approach conditions with solar arrays isolated as the outgassing source



Outgassed molecular contaminant that has experienced intermolecular collisions (and therefore would be ‘return flux’ if it hit the spacecraft)

Outgassing contaminant that has not experienced intermolecular collisions. The apparent dipolarity in the collisionless outgassing is due to the solar array orientation

Notional results – for discussion only

Conclusion

- Significant contamination control challenges associated with detection of organic compounds, and sample acquisition for potential return to Earth, are being addressed in the design of current flight projects and conceptual mission studies at JPL
- Mission specific challenges being addressed by the Mars 2020 and Europa Clipper missions are used to illustrate the unique character of contamination control activities supporting these missions
- Challenges illustrate the multidisciplinary aspect of contamination control engineering for space exploration missions, and the diversity of problems associated with detection of organic compounds, and sample acquisition for potential return to Earth

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